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Executive Summary

The purpose of this paper was to serve as a literature review overviewing the current state of knowledge pertaining to respiratory heat and moisture exchangers (HME's). Recommendations were extracted from the review with the intention of informing the Dwyer Hill Training Centre so that an informed decision could be made regarding further laboratory testing of HME's as well as setting policy regarding the use of HME's as an ergogenic aid for the Canadian Forces (CF). Detailed for the reader were the general physical properties and mechanism of function of most modern HME's, as well as their application to respiratory heat and moisture retention, reduction of cold and/or exercise induced bronchoconstriction, and medical environments. Although the majority of the papers reviewed reported positive findings—with the only real challenges coming from the medical community—no hard evidence was found to support the use of HME's as an ergogenic aid in the reduction of respiratory heat and moisture loss. However, there may be some merit for the use of HME's as performance enhancers by those individuals who are predisposed to respiratory complications that are further aggravated by cold and/or exercise exposure. In light of the evidence provided by this review, it is the recommendation of the authors that further more specific and thorough testing be commissioned to evaluate the heat and moisture sparing properties of HME's and their possible application as an ergogenic aid to CF personnel during cold exposure. We do feel comfortable however with recommending HME use by those military

personnel who have existing respiratory conditions that might be aggravated by cold and/or exercise exposure.

1. Introduction

It is commonly known that prolonged and at times acute exposure to cold environments can result in the onset of various respiratory and physiological complications, such as cold induced bronchiospasm and in more severe cases cold injuries and hypothermia. Some of these problems can be further complicated if the individual is asthmatic and/or engaged in mild to intense exercise or physical exertion (Gravelyn and Eschenbacher, 1986; Farley and Patel, 1988). Although it might seem ideal to avoid exposure to these conditions by staying indoors, certain groups such as the police, military, outside workers and various search and rescue personnel cannot afford this luxury. The common question for all of these organizations is how can they maximize exposure and consequently performance in cold environments for prolonged periods of time without succumbing to the hazards of the exposure? The answer to this question has come in the development of a plethora of protective clothing, body heating/rewarming, and respiratory inhalation devices or techniques designed either to prevent or recover from cold stress. One of these devices that has been mainly used for clinical applications for over 30 years is the heat and moisture exchanger (HME). A heat and moisture exchanger is a device which is designed to capture some of the energy and moisture contained in a subjects breath, and to transfer it to the inspired air. Although several models of HME are available on the market for clinical use, a new category of body heat retention mechanism have been marketed for outdoor activities. Claims by the

manufacturers of heat sparing properties and enhanced exposure/performance time in cold environments do seem ideal, and the devices themselves do seem practical for field application.

Recently, the Dwyer Hill Training Centre (DHTC) tasked DCIEM to conduct a literature review on HME's. The purpose of the review is to define if further laboratory testing is required on HME for outdoor use. The objective of this report is to serve as a literature review focussing on the efficacy and practicality of HME use in cold environments in the reduction of respiratory heat loss, prevention of cold stress, and facilitation of enhanced exposure/performance time. Furthermore, from this review conclusions will be drawn and recommendations made to the DHTC on the requirement for testing of HME for use by the Canadian Forces.

2. Physical Properties and Mechanism of Function of HME's

Several models of HME's are available on the market (ie. respirators, face-masks, mouth-borne), as well as shapes, sizes, and methods of employment. The one feature common to most modern HME's is the presence of a hygroscopic, hydroscopic or hydrophobic chemical/substance treated filter/contact surface, or meshwork of other high performance material directly over or inserted into the mouth. It is this mechanism that is used for the exchange of heat and moisture between the inspired and expired air. Although no specific HME device is present, the porous material or fabric meshwork inherent in a variety of surgical face masks and even the common winter scarf can be considered to have heat and moisture exchange properties (see Johnson et al. 1987).

Most passive HME devices operate on the premise that expired gas cools as it passes through the filtering structure, thus transferring heat to its walls. As the gas cools, water condenses, and is retained in the structure. On inspiration, the heat and moisture retained is transferred to the colder and drier gas. The function of the HME should therefore be to minimize the total loss of respiratory heat and moisture, and ultimately benefiting the user by reducing body heat loss to the cold environment and by reducing the risks of bronchioconstriction for people susceptible to this medical condition.

3. Reduction of Respiratory Heat and Moisture Loss

Recent studies have suggested that HME's may be beneficial in the reduction of respiratory heat and water loss, as well as in the increase of inspiratory temperatures and humidity levels.

In 1987, Johnson et al. conducted a thorough study comprised of three separate but related experiments which formed the basis for their technical and functional assessment of cold weather masks in severe cold conditions. The overall purpose of the study was to determine the effectiveness of cold weather masks in reducing acute respiratory symptoms, to determine the effectiveness of the masks in increasing relative inhalation temperatures, and to evaluate the masks on ergonomic and technical characteristics. A total of 17 masks were divided into three categories before assessments began: Category 1 masks consisted of a porous material or fabric that covered the nose and mouth—such as a surgeon's face mask or a winter scarf; category 2 masks consisted of a holder such as an oxygen face mask equipped with an HME device made of porous material such as stainless steel mesh, paper fibers, or foam. Category 3 masks consisted of a corrugated, flexible tube (2.5 cm diameter) attached to an oxygen face mask and extended into a winter jacked where warm, non-humidified air could be drawn by the subject through a one way valve, and expired air exhausted through two vents on either side of the face mask.

The purpose of the first experiment was to evaluate the thermal, ergonomic, and technical characteristics of the cold weather masks, and to chose a small number of masks—based

on inspiratory temperature raising ability, public availability, and comfort—to be tested by a greater number of subjects. Two normal male subjects, aged 45 and 21 were asked to exercise on a treadmill at low (4.8 kilometers per hour and 0% slope) and medium (4.8 km/h and 6% slope) exercise rates for each of the sixteen masks on a day when ambient temperatures ranged from -1 to -3 degrees C. The first subject tested the first five masks, and the second subject tested the remaining masks. Trials for each mask were one minute long for both exercise rates, with the medium rate immediately followed by the low exercise rate for each mask. Control (no mask) trials were conducted at the beginning and midway points through the testing sequence, and after each mask was tested the subject completed a questionnaire indoors which was designed to evaluate various aspects of the mask such as comfort, fit, condensation, breathing, and aesthetics. Throughout the active testing, the subjects were instructed to breath through their mouths only. Inspiratory temperatures were recorded with a thermocouple wire positioned inside the subjects mouth centered within one half of a modified pulmonary function mouthpiece. To describe the masks thermal performance, the researchers defined and reported a performance coefficient (PC%) (see report for formula's used), where perfect heat exchange properties and return of all trapped heat from exhalation would yield a value of 100. The investigators observed an increase in inspiratory temperatures above ambient temperatures in all of the masks tested, with PC's ranging from (mean +/- SE) 20 +/- 1.7% for the scarf (category 1) to 55 +/- 0.9% for the Isolation mask (category 1). Category 2 PC's ranged from 30 +/- 0.7% to 55 +/- 0.9% for the Pall and Southwind Cold Weather Respirator respectively, while category 3 values were varied from 47 +/- 0.7% with the

Oxygen mask and tubing to 54 +/- 0.7 in the Cold Air Weather Mask. None of the category 3 masks were chosen for further evaluation in the second and third experiments because they were all considered to unwieldy, and were generally flawed technically. The Southwind was the only commercial HME accepted for further testing because it had the highest PC of all the masks, while the scarf was chosen because of its widespread availability, acceptability, and high ranking on aesthetics. In total five masks (three category 1 and two category 2) were chosen for experiment 2, while the others were rejected based on technical, thermal, or subjectively rated flaws.

The second experiment was designed to further test 5 selected weather masks for their effectiveness in increasing inspiratory temperatures, as well as their ergonomic and technical characteristics. The results were ultimately used to select the 3 masks that would be evaluated in experiment 3 for their effectiveness in reducing acute respiratory symptoms. Researchers recruited three males and two females, all without respiratory problems and asked them to exercise at the low intensity rate used in experiment one (on the same treadmill) on a day when ambient temperatures ranged from -18 to -10 degrees C. Each subject was given a ten minute warm up on the treadmill, after which the masks and a control (no mask) were tested in random order for three minutes each. During the trials temperature readings were taken at the mouth with the same equipment set up previously described. After each mask was tested, the subjects were instructed to go indoors for approximately five minutes and complete the same questionnaire that was used in experiment one. All of the masks tested were found to be effective in increasing inspiratory temperatures. The PC's ranged from 52 +/- 2.7% to 73 +/- 1.5% for the

Brethaid and Southwind models (both category 2) respectively. The researchers observed all masks to have a PC equivalent to or higher than those values obtained in the first experiment. (note: Mekjavic and Eiken study (1996) also found PC's to be higher in colder ambient temperatures). The Brethaid was not selected for experiment three because it was not commercially available and had a low PC (53%), while the scarf was not further evaluated because it had the same low PC (53%), but also because it is not sold specifically to reduce respiratory problems. Although the no mask condition yielded a PC of 33 +/- 2.6 % rather than the 0 that simple theory (PC formula) would have predicted, the researchers quickly disregarded it mentioning that this was the result of condensation on the thermocouple.

Johnson et al. also found positive results in the third phase of their study which evaluated selected cold weather masks for their effectiveness in reducing cold induced respiratory symptoms. Readers are directed to the second theme (role in cold and/or exercise induced bronchoconstriction) of this review where they will more conveniently find a summary of this experiment.

Since all of the cold weather masks tested warmed the otherwise chilly air the investigators concluded by suggesting that users are able to chose the masks most suitable to their individual tastes. For economy's sake the investigators suggested that a person should try out a scarf in cold weather before buying any of the commercially produced cold weather masks. To obtain the best results they recommended that all the respired air should pass through the heat and moisture exchanging fibers of the scarf, and for the scarf to be knotted tight enough so that air leakage around the edges is kept to a minimum.

Additionally, they suggested folding the scarf in duplicate if possible. Johnson and colleagues concluded that an aesthetically pleasing and effective combination would be a cold weather mask covered by a scarf, since the surgical masks fit relatively snugly against the face. However, to achieve optimal warming effects (ie. highest PC) in extreme cold environments, the authors recommended the Southwind—an HME equipped face mask.

Rosen and Rosen (1995) examined the effect of a face-mask (Air Warming Mask, 3M, Minneapolis, MN) on respiratory water loss during sleep in cold conditions. In a crossover design study 10 subjects (8 male, 2 female) between the ages of 23 and 40 slept alone in mountaineering tents on two winter nights (8 hours each night) with ambient temperatures of less that 0 degrees Celsius. On one night they wore heat and moisture retaining masks, and on the other night they wore no mask. Subjects were weighed before and after each session to obtain an estimate of respiratory water loss (urine and insensible losses taken into consideration), and comparisons were made of weight loss with and without the mask. The investigators observed a mean reduction in weight loss of 0.13 kg (SD 0.18 kg), which was found to be significant at the $p<.05$ level using a one tailed *t*-test. They reasoned that since respiratory heat loss is primarily due to respiratory water loss, and the evaporation of 1 gram of water represents 0.54 Kcal, this seemingly small number of calories could on a long trip lead to accumulated calories conserved that do not have to be packed. They pointed to the fact that respiratory heat loss represents 25 to 30 % of resting metabolic rate, suggesting that this type of heat conservation could be important, especially for a physically exhausted individual trying to sleep in the cold. Ultimately, the investigators concluded that on long cold weather trips, especially those on which

conserving fuel and minimizing weight are important, an inexpensive and lightweight face mask worn during the hours sleeping in a tent may meaningfully reduce respiratory heat and water loss.

In another study (Mekjavic and Eiken, 1995), investigators evaluated the efficacy of inhaling warm moist air as a method of rewarming from hypothermia in –20 degree Celsius (C) field conditions. The inhalation rewarming method was compared to passive rewarming, and passive rewarming using a respiratory heat exchanger. The eight male subjects were rendered hypothermic on three occasions by immersion in 15 degree C water for one hour. After which they were placed in a well insulated sleeping bag and transferred to a –20 degree room for rewarming with each of the three methods. Study results showed inspired air temperature to be –19.4 +/- 1.1, +20.5 +/- 1.2, and +36.2 +/- 2.9 degrees C for the control, HME, and inhalation rewarming trials respectively. The investigators observed a reduction in the post exposure drop in rectal temperature (afterdrop) with the inhalation rewarming method. Since the magnitude of the reduction was similar to that observed with the HME, they suggested that the results might be attributed to the minimization of respiratory heat loss. The study did not find the HME (Goodfellow Corp., Malver, PA) or inhalation rewarming device—Heat Treat (Thermogenesis, Victoria BC) to be useful in improving the rate of rectal temperature rewarming in well insulated shivering subjects in a –20 degree ambience. The authors did however point to a possible advantage of the HME in its ability to prevent respiratory heat loss without attenuating shivering thermogenesis. Where as inhalation rewarming, might—by providing a warm stimulus to the facial area and directly heating the

hypothalmus—attenuate shivering, consequently diminishing any benefit from this endogenous heat. A final advantage of the HME mentioned lies in its greater practicality and therefore applicability to field conditions.

Support for the use of the above mentioned HME comes from another study conducted by Mekjavic and Eiken (1996) which examined the thermodynamic characteristics, and efficiency of a prototype respiratory heat and moisture exchanger (Goodfellow Corp., Malver, PA) over a range of simulated ambient temperature conditions. In this experiment the investigators strapped the HME to the head of a manikin whose mouth was connected to a respiratory simulator. The simulator was connected to a valve arrangement, such that the expired gas was drawn through a water bath and through the HME. On inspiration the gas was returned to the breathing simulator. The water bath functioned to regulate expired gas to 37 degrees C, saturated with water vapor at approximately 43 degrees C. The entire arrangement was placed in a climatic chamber where the HME was evaluated at ambient temperatures of –24 +/- 0.3, -13.8 +/- 0.5, -3.8 +/- 0.3, 8.2 +/-0.1 and 21.7 +/- 0.03 degrees C, and at two levels of ventilation (VE); 11.25 liters per minute (rest) and 28 liters per minute (light exercise). Temperatures within the oro-nasal mask of the HME were measured with a T-type thermocouple, with recordings made at 0.9 second intervals, and measurements taken for a one minute period for the two levels of ventilation. HME efficiency was then evaluated by determination of the performance coefficient (PC %), as suggested by Johnson et al. (1987). At –24 degrees C and resting VE, expired and inspired air temperature were found to be maintained at 34.9 +/- 0.4 degrees C, and 22.2 +/- 0.2 degrees C respectively.

Increased VE resulted in expired temperatures of 36.3 +/- 0.7 degrees C and inspired temperatures of 24.9 +/- 0.6 degrees C, thus elevating the inspired air temperature by 47.4 +/- 0.6 degrees C from the simulated ambient condition of -24 degrees C, while maintaining the humidity at the oro-nasal mask near saturation through out the trial. The investigators observed PC's of 78.4 +/- 0.8 %(VE = 11.25 L/min) and 80.6 +/- 0.6 %(VE = 28 L min) in the –24 degree C condition, but also found PC's to decrease progressively as temperatures came closer to and above 0 degrees C. Furthermore, PC's for the higher simulated VE were consistently larger than those observed at lower levels of ventilation for each of the ambient conditions tested. The PC's determined were found to be well above those reported (Johnson et al) for 17 (actually 16, as one—The Cold Weather Mask, Trudell Med.—was mentioned but not tested because it was no longer available) other cold weather masks. Mekjavic and Eiken concluded that the prototype HME was capable of reducing respiratory heat loss in ambient conditions ranging from –20 to + 20 degrees C at ventilation rates associated with rest and light work conditions. The apparent value of this study lies in the possible application of its findings in the development of a more refined mechanism that can be used by workers and recreationists alike to make work or play conditions more bearable while also functioning as a performance enhancer in a practical, non-invasive way. It should be noted however that no human subjects were used for the evaluation of the HME. Furthermore, it should be stressed that the problem in testing the performance of HME's by mechanical means is the inability of the test rig to simulate the lower airways ability to generate moisture—unless the test rig is set up to do so (as in the 1987 evaluation report on

HME's originally published by the U.K. Departments of Health and Social Security). Mekjavik and Eiken used a lung simulator that exhaled saturated gas at all minute volumes. This has been said to be unrealistic as it would tend to show a better performance than would be obtained clinically (see report referenced above). Consequently, it is for this reason that the PC's obtained by these investigators might have been higher than those obtained by Johnson et al. who used human subjects in their study. The value of this study would have been more promising if the researchers had used human subjects or a test rig that could saturate the air at lower minute volumes, but exhale air with reduced humidity as minute volume increased (see test rig used in evaluation report cited above).

In 1998 Intertek Testing Services (ITS)—an independent non-clinical laboratory based in Atlanta—was commissioned by the PolarWrap company to evaluate and provide a report on their newly designed Thermal Exchange Device. The device basically consists of a compact HME placed nicely within a winter face garment, such that it is designed to pre-warm and pre-moisten air that is inhaled in cold and dry ambient conditions. Consequently, the purpose of the study performed by ITS was to evaluate the performance of the device at a variety of ambient temperature conditions. Two subjects were used to evaluate the effectiveness of one camouflage device during a series of varied testing parameters which included: ambient temperatures (degrees C) of -20.6, -15, -12, -3.9; relative humidity at approximately 10%; breathing rates of 10 or 20 respiration per minutes, and usage period. The protocol involved prewarming the device by breathing in and out through the heat exchanger for a one minute period, after which the subjects were

placed into the cold ambient conditions where they were to breath through the device for one minute (note: A control test was also performed using no device). Thin wire T thermocouples were attached to the center of the air inflow and outflow ports of the device so that the temperature of the air at the interior and exterior ports could be measured during inhalation and exhalation. A thermocouple was also used to measure ambient temperature, and Vaisala humidity probe was used to measure the relative humidity of the inhaled and exhaled air during some of the tests. ITS concluded by stating that the test results demonstrated that, after a one minute stabilization period, the device performed as intended. They mentioned that even as temperatures went down to -20 degrees C, the temperature of the inhaled air for both subjects did not drop below 29.4 degrees C (with the device held firmly over the mouth) and below 26.7 degrees C (with the device held in place with the Velcro fasteners. When no mask was used, the average inhaled temperature would decrease to 18.3 degrees C at an ambient temperature of -3.9 degrees C (relative humidity of 10% for subject B at a respiratory rate of 20/minute. When no mask was used for subject A, the average inhaled temperature would decrease to 34.4 degrees C at an ambient temperature of -3.9 degrees C (8% relative humidity) and respiratory rate of 10/min. Furthermore, the assessment showed the relative humidity of the inhaled air to be raised from less than 10% to approximately 75%. ITS also concluded that breathing rate did not have a significant effect on the performance of the device. In spite of these positive findings, it is important to note that there is a large unexplained difference in the average inhaled temperatures observed between subjects A and B when no mask is being used. Furthermore the report by Intertek makes no mention of how

these temperatures were measured when the subjects were not wearing the mask. The methodology used in this study is also questionable, as there are too many variations—and hardly any similarities—in the conditions employed for subjects A and B to be able to make the necessary comparisons between the mask and no mask conditions. Finally, it is not known whether the investigators were aware of the considerations for temperature measurement errors that are associated with the use of thermal probes to measure temperature in cold ambient conditions (see discussion for more details on as it relates to most studies using these devices to measure inspiratory temperatures in cold environments). It is not likely that polar wrap can justify the claims they have made regarding the use of their thermal exchange device based on the findings of this study.

4. Role in reduction of respiratory and cardiac stress

An additional function of HME's that was studied is its potential role in the reduction of respiratory and cardiac stress during cold exposure, particularly during exercise. Only one study investigated this role, and the study was commissioned by the manufacturer of the HME PolarWrap (PolarWrap LLC, Memphis, TN). The study involved two cold trials performed at -20°C while the 11 subjects exercised at 60% of their VO_{2max}. Spirometric [Forced Vital Capacity (FVC), and Forced Expiratory Volume (FEV)] and physiological parameters [heart rate (HR) and Mean Arterial Pressure (MAP)] were recorded during the trials (Human Performance Laboratory, 1999). It was reported that FVC improved by 4% and FEV by 3% by using the HME during exercise as compared to the control test without HME. HR was reported not to be affected by the use of HME during exercise, while MAP was reported to be significantly lower by 6% during the exercise period with HME.

The results of this study showed that significant improvement of the spirometric and physiological parameters were observed while using the HME during exercise in the cold.

5. Role in Cold and/or Exercise Induced Bronchoconstriction

Existing evidence suggests HME use to be an effective mediator in the reduced risk of onset of cold and/or exercise induced bronchochonstriction in asthmatic and non-asthmatic subjects alike.

In a letter to the editor printed in The New England Journal of Medicine, Levin (1978) proposed an efficient, practical, and non-pharmacologic solution to exercise induced bronchospasm. Her anecdotal suggestion involved placing a surgical face mask containing several moistened gauze sponges over the nose and mouth which would eliminate pollen, and warm and humidify inspired chilly air. She claimed that the further addition of petrolatum to the nares and inner canthus of each eye (plus ski goggles during heavy pollen days) would give further protection and permit many otherwise 'impossible' tasks. She maintained that the mask solution was frequently offered to students who complained of allergies preventing them from helping with housework or for those who felt unusually ill after outdoor sports during pollen season.

In another letter to the editor (New England Journal of Medicine), Schacter et al. (1978) attempted to increase the plausibility of the anecdotal suggestion made by Levin in an earlier issue by providing supporting references as well as the findings from their study which evaluated the potential use of a simple mask in the prevention of exercise induced asthma. They recruited six asthmatic subjects with previously demonstrated exercise induced bronchospasm to exercise on two separate days on a Monarch cycle ergometer

up to submaximal loads. The same workloads were repeated at the same time on each day for individual subjects, which eliminated the possibility of diurnal variation. The trials were performed in a temperature regulated laboratory (24.4 degrees C, 60% relative humidity), where on the first day subjects exercised breathing air freely through the nose and mouth as opposed to through a Micropore mask (2643, 3M St. Paul Minnesota) on the second day. Pulmonary function was measured before and after exercise on maximal and partial expiratory flow-volume curves. When flow rates at 60% of the vital capacity below total lung capacity were analyzed, the investigators observed a significantly ($p < 0.05$ by paired t test) less pronounced reduction in flows after exercise when the subjects wore the protective mask (mean +/- SEM of 39.8 +/- 12.3%) versus the no mask condition (mean +/- SEM of 62.0 +/- 11.8). The authors concluded that the preliminary study suggested that partial rebreathing of warmed humidified air might blunt exercise induced bronchospasm. They also indicated the potential usefulness of wearing protective masks during exercise for asthmatic patients with known exercise induced bronchospasm.

A 1980 study by Brenner et al. was conducted to verify the previous reports of Levin (1978) and Schacter et al. (1978) through an evaluation of the effectiveness of a portable surgical face mask in attenuating exercise induced asthma (EIA). Although no HME device was present, the authors hypothesized that simply covering the nose and mouth with a mask would enable the subject to retain heat from expired air. Therefore conditioning the airways, and possibly having the same effect in preventing EIA as heated humidifiers appear to. Ten children (five boys, five girls) between the ages of ten to

fifteen participated in the study. All were patients of the National Asthma Centre (treatment center for severe asthmatics), had a history of EIA, and taking long acting medication for their condition. On two successive days (one without mask, one with mask) the subjects performed a modified six minute standardized treadmill test where the grade and speed of the treadmill were adjusted to achieve an exercise heart rate of 90% of the age predicted maximum for the last three minutes of running. Pulmonary function parameters were assessed before testing and at 3, 6, and 12 minutes after exercise within the laboratory (ambient temperature 23 +/- 1 degree C, 26 +/- 2% relative humidity). Measurements obtained included a forced vital capacity (FVC) in duplicate which allowed for the assessment of forced expiratory volume in one second (FEV1), and maximal midexpiratory flow rate (MMEF). All testing was performed at the same time of day for each subject, six or seven hours after morning medications had been taken, and on days where not steroid therapy was administered. On the control day—breathing room air—the investigators observed average baseline FEV1 and MMEF values of 96 +/- 4% and 61 +/- 6 % (+/- SE) respectively, of predicted values. At all times they found a marked drop in both indices post exercise, which were most pronounced at the six minute mark. Significant (Students *t* test, $p < .01$) decreases in FEV1 and MMEF to 66 +/- 6% and 47 +/- 4% respectively of the pre exercise baseline values were reported at the six minute mark. On the mask day, baseline FEV1 and MMEF values were similar to those observed on the control day (94 +/- 4% and 62 +/- 4% respectively of predicted values). However, significant (student's *t* test, $p < .01$) six minute post exercise decreases in FEV1 and MMEF only fell to 91 +/- 3% and 82 +/- 5% respectively of the pre exercise baseline

values, and a near normal return was observed at the 12 minute mark. The investigators used a two way ANOVA to show that the drop in pulmonary function values were significantly ($p < .001$) less overall for the mask session. Furthermore, additional paired *t* tests comparing the pulmonary function indices at three and twelve minutes after exercise were also observed as being significant (*p* FEV1: 3 min. < .01; 12min. < .05. *p* MMEF: 3 min. <.001; 12 min. < .01). Brenner and his associates suggested that covering the nose and mouth with a mask necessitates the rebreathing of expired air that has been warmed and humidified by its passage through the respiratory tract. The investigators observed temperatures of 34 degrees C behind the mask (in front of the lips), and although humidity measurements of expired air at the lips were not taken, they cited a study that reported this to be 34 to 36 mg of water per liter. Although a placebo effect could not be totally excluded, the researchers concluded that a simple face mask appears to be effective in attenuating EIA, emphasizing the importance of airway cooling as the stimulus for EIA, and may provide a practical, nonpharmacologic alternative for asthmatic runners and skiers.

Gravelyn and Eschenbacher (1986) examined the effect of using an HME (Siemans-Elma) to condition inspired dry air in asthmatics. They studied 9 non-smoking subjects (6 female, 3 male between the ages of 19 to 32) who all had a documented history of reversible airways obstruction, and demonstrated a greater than 100% increase in specific airway resistance (SRaw in LxcmH2O/L/s)—an indicator of bronchoconstriction—to isocapnic hyperpnea with dry air. Volunteers were randomized for two days of testing (one with HME, and one without), where on each day they first

had a baseline determination of SRaw before they performed isocapnic hyperpnia (rapid and exceptionally deep breathing, or abnormal increase in the depth and rate of respiratory movements) with room temperature dry (0% relative humidity) air at 55-75 liters per minute (L/min.). Immediately after and five minutes after completion of hyperpnea, repeated measures of SRaw were taken. At ventilation rates of 67.7 +/- 1.6 L/min the investigators observed post and five minute post hyperpnea SRaw values of 24.4 +/- 5.8 and 23.3 +/- 3.9 respectively in subjects not using HME's who had a baseline SRaw of 6.1 +/-0.6. Subjects at similar (65.2 +/- 2.2 L/Min) ventilation's with the HME's in place recorded baseline, post, and five minute post hyperpnea SRaw values of 7.1 +/- 0.9, 7.6 +/- 1.3, and 6.9 +/- 0.9 respectively. The investigators observed a greater than 100% increase in SRaw without the HME's , but found subjects well protected from bronchoconstriction with the HME's in place ($p.< 0.1$) They suggested that respirators or face masks with hygroscopic material as found in HME's should protect patients with asthma who exercise or walk in cold, dry air.

Favorable results in the reduction of exercise induced asthma were also reported in a third experiment conducted by Johnson et al. (1987). The purpose of this final phase of their three experiment design study was to evaluate selected cold weather masks for their effectiveness in reducing cold induced respiratory symptoms. Five males and three females, all with cold induced respiratory problems (mild asthmatics to chronic bronchitis with emphysema) participated in the experiment, which was conducted on a day when ambient temperatures were less than -20 degrees C. Each subject walked on the same treadmill used previously, adjusting the speed to their normal walking rate (not

necessarily the 4.8 km/h used previously) at a 0% slope. Researchers assessed the three masks in random order, with each sample being worn for five minutes and the control (no mask) being tested at the end of the sequence. Each subjects trial began with a spirometry measurement taken indoors followed by the same baseline readings taken outdoor, which were immediately followed by the exercise trials. Spirometry readings were also taken one and five minutes post exercise, and assumed by the investigators to reflect the effects of the masks on pulmonary function and normal baseline values respectively. The mask effects on FEV1 (forced expiratory ventilation in one second; A spirometrical measure used to assess the degree of pulmonary restriction or obstruction to airflow which is usually found to be worse [corresponding to a lower percentage] in diseased [ie. asthmatics] versus non-diseased populations when compared to others of the same age, sex and height)) were shown by calculating %FEV1 using a formula, where the researchers corrected for standard BTPS volume and air leakage from the spirometry bag (see article for calculations). The subjects were asked to wear the masks outdoors for a trial period of two weeks, after which they were interviewed on a telephone for their comments. Using a one way ANOVA the investigators observed a statistically significant difference ($p< 0.05$) in % change in FEV1 from baseline values between the conditions (3M surgical mask [category 1] 102.09 +/-3.39%; Spenco cold air mask [category 1] 102.89 +/- 2.25 %; Southwind cold weather respirator [category 2] 106.81 +/- 4.87%; No mask 87.96 +/- 10.93%. Additionally, when a Newman-Keuls test was applied to the data, no significant difference between the three masks was observed, however all three masks were significantly different than the no mask condition. Thus the pulmonary function

data indicated that all of the three masks prevented or even reversed spirometric decline. Investigators reported that some patients who functioned normally with a mask had to stop with no mask. Additionally, breathing problems which were not reported by patients while wearing a mask were reported when not wearing a mask. Based on this evidence Johnson and his colleagues concluded that the cold weather masks did remedy cold induced respiratory symptoms at ambient temperatures of less than -20 degrees C.

In a 1989 study, Eiken and associates evaluated the physical properties of a mouth borne HME (Lungplus ®, Lungplus Info AB, Malmo, Sweeden), and its effect on subjective (rating of perceived exertion—RPE; breathing resistance—RPBR; breathing discomfort—RPBD) and objective (VO2; VE: inspired/expired breathing resistance) performance variables during high intensity exercise in a cold environment. In a single blind alternating order experimental design, nine healthy male subjects [29 (21-32) yr, 178 (173-186) cm, and 73 (61-88) kg] performed two incremental load cycle ergometry tests (once breathing through an HME and once through an identical control mouthpiece) to exhaustion in a climatic chamber set at –15 (-14 to-16) degree C. Time to exhaustion, oxygen uptake and VE were not affected with the HME in place. The investigators did find, however that the HME substantially increased ($p < 0.001$) inspired and decreased ($p < 0.01$) expired mouth measured gas temperatures; at 260 watts (W) work load at VE of 100 liters per minute these changes amounted to single recordings of +15 degrees C and –5 degrees C respectively. The investigators observed increased breathing resistances with the HME (ie. at 200 watts mean airflow rate = 1.21 s –1) about three times higher than in the control condition, with the effect being even greater at 290 watts (mean airflow rate =

1.91 s – 1). These values however were reported to remain within tolerable levels even during severe exercise. Furthermore, subjective assessments of breathing resistance, and discomfort were rated similarly in the HME and control conditions. Eiken et al. concluded that since it appeared that the HME provided a good heat (and therefore moisture) exchange function while keeping breathing resistance relatively low even at high pulmonary ventilation's, this suggests HME use to be a useful aid for individual suffering from cold induced bronchospasm. They also mentioned that HME's may be used by healthy individuals during exercise in a cold environment without interfering with performance.

Stewart et al. (1992), investigated whether using a mask that retains heat and moisture prevents the development of exercise induced asthma. In this cross over design study four female and six male (12-26 yr.) patients with asthma whose condition had been stable for several months and with symptoms being induced by exercise were randomly assigned to either an HME (face mask with filter—Filtrguard mask (Intersurgical, Middlesex) or control (no mask/filter) group. No oral medication was allowed on the days of exercise, and inhaled drugs were omitted for at least six hours. Baseline levels of forced expiratory volume in one second (FEV 1) were obtained after 20 minutes of rest, after which exercise was performed either on a cycle ergometer (3 subjects) or treadmill (7 subjects) until a heart rate equivalent to 80% of the maximum predicted for age and sex was achieved. The cross over was run at the same time of the day one week later, and subjects used the same exercise machine as in the first test. The investigators calculated the percentage reduction in FEV 1 after exercise using the pre

exercise value as the baseline value, obtaining statistical significance with a student's paired *t* test. The investigators observed a mean reduction in FEV 1 of 33.7 % (SE 3.2 %) without the mask and 9.1 % (SE 6.1 %) with it ($p < 0.01$). Only one subject showed no improvement with the mask, and although most felt heat on their face, no subjects complained of difficulty in breathing though the mask. Stewart and co workers concluded that a mask retaining heat and moisture effectively controlled exercise induced asthma in most of their asthmatic subjects, and that the increased dead space from the mask does not play an important part during exercise. They suggested storing exhaled air in a mask such as the one used in their study to be a practical way to humidify and heat inspired air, further indicating that the mask might be more beneficial in cold weather which classically precipitates the onset of exercise induces asthma. The 9.1 % post exercise reduction in FEV 1 with the mask was found to be similar to that produced by a drug used for the past 20 years in treating exercise induced asthma (sodium cromoglycate). The investigators further mentioned that although Beta 2 agonists often completely eliminate the drop in FEV 1, their stimulant effects might be disadvantageous in some athletic contexts. Therefore ultimately concluding that masks may be helpful in the management of subjects who cannot or will not take prophylactic drug treatment.

In a three experiment study design, Nisar and colleagues (1992) described the characteristics of a new HME mask, and assessed its effectiveness in warming inspired air as well as on the severity of exercise induced asthma.

The new design heat exchanger element studied consisted of a low mass/high surface area aluminum (3-6 mm) honeycomb matrix supported between two 0.1 mm polypropylene

mesh layers which ensured turbulent airflow through the matrix, and thus good air matrix contact. The whole element had an area of 25 cm squared and a depth of 2 cm. Resistance to airflow was negligible at low flow rates, only reaching 0.17 cm H2O/l/s at flow rates of 6 l/s. The was said not to saturate, even with prolonged use because of the loose nature of the matrix. The HME was incorporated into a light weight (75 g), washable, and sterilizable face mask.

The investigators obtained measurements for temperature, end tidal carbon dioxide concentrations, and spirometry. Air temperatures were measured immediately proximal and distal to the HME element and recorded with fast response type K thermocouples. The temperature difference across the HME within each breath was recorded, and the average temperature (end expiratory temperature—end inspiratory temperature) was calculated for each of 10 to 15 successive breaths, where mean values were obtained in the second and last minute of each exercise test.

Statistical comparisons were performed with non-parametric Wilcoxon signed rank tests or by Student's paired test.

The first experiment assessed the effect of breathing pattern on the efficacy of the mask. Four normal subjects were instructed to first breath through the mask (dummy and active) with tidal breathing for 5 minutes followed by 15 seconds of maximum voluntary ventilation (MVV). This was done first with room air set at 24 degrees C and then with the mask connected to a supply of -13 degree C air from a cold air generator. The investigators observed inspired temperatures of mean (+/- SD) 32.5 (1.4) degrees C with the HME and 26.2 (0.5) with the dummy mask when subjects breathed 24 degree C room

air quietly. They did not find the increased flow rate across the device during MVV to significantly affect the inspired temperatures. The investigators did however find an increased difference in the mean inspiratory temperatures between active [22.9 (1.1) degrees C] and dummy [8.5 (2.5) degrees C] masks at the -13 degree C ambient condition. Temperature gradient across the device was observed to be independent of flow rate.

The second experiment consisted of eight patients (four males and four females, mean age 27 years [range 13-42]) with clinical history of bronchoconstrication after exercise. All subjects regularly used *B* agonist inhalers, six were also using an inhaled steroid, and three an oral theophyline preparation. Each subject participated at the same time on three consecutive days, without taking the *B* agonists for at least six hours, and the orals for 24 hours. After resting for 30 minutes baseline measures of forced vital capacity (FVC) and FEV1 were obtained, where mean FEV1 was found to be 2.7 l (99% of predicted values). A six to nine minute cycle ergometer exercise test with a workload of 50 or 75 watts was fixed for each subject for all three days, and FEV1 and FVC were measured again at the end of exercise and at three minute intervals until baseline FEV1 was reached. On the first day the subjects breathed through a cardboard tube mouthpiece, while on the next two days the tube was randomly replaced with either a control (black rubber anaesthetic mask with similar dead space) or active mask. The investigators recorded heart rates before and after exercise, and subjects continued to wear the masks after exercise except when spirometric measurements were being recorded. Researchers found mean inspired air temperature gradients of 2.4 (range 0-5) and 6.3 (range 5-7.9) degrees C respectively across the control mask and HME device, with constant mean inspired air temperatures

for each subject during the six minute exercise bout. All subjects developed exercise induced bronchoconstriction on the first study day with an observed median (range) fall in FEV1 of 0.8 (0.4-2.6) l, while falls to 0.6 (0.4-2.0) l and 0.3 (0-2.2) l were observed with the control and HME masks respectively ($p< 0.02$). The timing of the FEV1 return to baseline after exercise was not found to be affected by the masks.

Seven more subjects (three male and four female) with a mean age of 23 (range 19-30) were recruited to participate in the third phase of the study. They had a mean FEV1 of 3.7 l (98% of predicted values) with a history of exercise induced asthma. All subjects were using inhaled *B* agonists with two taking an inhaled steroid, however the agonists were not taken for at least six hours before each study (steroids continued to be taken). Subjects attended on two consecutive days at the same time of the day, breathing through the active HME or control mask of similar appearance in random order. They exercised for six minutes on a cycle ergometer where the workload was adjusted during the first two minutes of day 1 to achieve a workload of 75% of the predicted maximum for that subject. In this experiment the masks were connected to a supply of cold air (-13 degrees C) from a cold air generator. The investigators observed mean inspired air temperature increases of -13 to 10 (5) degrees C with the control mask and to 19 (7) degrees C with the HME mask. They found no significant differences in pre exercise spirometric results and maximum heart rates for the two test days. Mean arterial oxygen saturation was found to be similar on both days, however the investigators did note significantly ($p <$ 0.02) lower end tidal carbon dioxide tension during exercise on the day when the control mask was used (3.73 (0.11) kPa) compared to the HME day (3.97 (0.11) kPa). All

subjects wearing the control masks developed exercise induce bronchoconstriction, with the observed median (range) fall in FEV1 being 0.8 (0.5-1.5) l. The investigators recorded significantly ($p< 0.02$) lower median FEV1 falls in subjects wearing the active masks. The observed time course of bronchoconstriction varied between patients, but was generally similar with the active and control masks. Immediate bronchodilation after exercise was seen in four subjects when wearing the active masks, and in none of the subjects when wearing the control masks. Recovery from exercise induced bronchoconstriction was found to be faster with the active mask (median time to recovery 12 minutes). Furthermore, FEV1 return to baseline values occurred within 30 minutes in all subjects using the HME mask compared to only three with the control mask. Finally, all patients reported the masks as being comfortable to wear.

From this triad of experiments, Nisar and his colleagues concluded that the described new HME mask could raise the inspired temperature and humidity, and reduce the severity of exercise induced bronchoconstriction in the laboratory. They mentioned that such a device might be of practical value for asthmatic patients in non contact sports or for workers in cold storage units. Furthermore, they suggested that this approach to air temperature regulation might prove useful for other patients in whom cold air can provoke symptoms

6. Medical Applications

Although more conflicting evidence exists, some medical research on HME use suggests that these devices may possibly serve as a useful tool to condition air and aid in the prevention of hypothermia during surgery.

One must remember that although the HME's for clinical use have been subject to much scrutiny and evaluation, these studies were not carried out in subzero ambient temperatures, and subjects were either undergoing surgery or mechanically simulated. Consequently these findings are limited in their generalizability to field applications.

In 1987 an evaluation report containing extracts from Health Equipment Information (HEI 166)—published by the U.K. Departments of Health and Social Security—provided a thorough examination and review of 12 HME's. The report included a technical background, historical development, as well as clinical applications, advantages, and hazards of HME's before going on to describe the specific test rig used for the evaluation. The test rig was designed so that a breathing simulator could replicate the varied humidification levels of human breathing—ie. it could saturate the air at lower minute volumes, but exhaled air with reduced humidity as minute volume increased. The individual HME's were placed within the circuit, where mean airway humidity on the patient side of the devices were evaluated in accordance with the ISO (International Standards Organization) standards for humidifiers (30 mg/L as a minimum humidity to be delivered to patients with an upper respiratory tract bypass, and 10 mg/L for where it is only required to approximate environmental humidity). The HME's evaluated were generally single use disposable, hygroscopic, hydroscopic, or hydrophobic filters

designed for use by patients whose upper airways are bypassed during artificial ventilation, are tracheotimized, or breathing spontaneously. In the tests reported dry air [dew point –50 degrees C] was provided by the simulator at a temperature of between 19 to 24 degree C, and at different levels of ventilation. The humidifying effect of the breathing circuit itself was cancelled out. Technical aspects of the HME's were also evaluated. An overall comparison of the 12 HME's tested found little difference in their heat conserving ability, as all were able to restore the temperature of the breath inhaled by the lung simulator to within 3 degrees C of that exhaled. None of the devices could provide as much heat and moisture to inspired gases as heated humidifiers can . Except at extremely low minute volumes none were able to reach the 30 mg/L ISO standard. The devices were found to be able to maintain the mean humidity in the airway on the patient side of the HME's above the environmental level of 10 mg/L at ventilation rates of up to 30 L (number varies with HME). However, humidity had a tendency to fall (at varying rates) as flow rates were increased. The report recommended that as little extra volume as possible should be added to a breathing system. Two HME's from the group were suggested as being most useful at low (Gibeck humidvent 1) and higher (Siemans Servo 150 and 151) minute volumes.

A 1992 abstract by Deriaz, Piez, and Lienhart reported whether the use of a hygrophobic filter (Pall, Ultipor) or a heated humidifier (Drager, Aquapor) during surgery had any effect on a patients intraoperative core temperature and thermal balance. They randomly assigned 75 patients scheduled for gynaecological surgery into three equal groups, where group A served as control, group B utilized a hygrophobic filter set up

between the endotracheal tube and Y piece, and group C were equipped with a heated humidifier set at 41.5 degrees C (100% saturation). The patients were all anaesthetized with the same technique, and no differences existed between groups as far as age, drug doses, perfusion volumes, and room temperatures. Room, tympanic, rectal, oesophageal and four skin (thorax, arm, leg, thigh) temperatures were measured with calibrated thermistors, on arrival in the operating room, during induction, every 10 minutes for two hours, and every 20 minutes for two hours more. The investigators used Ramanathans's formula to calculate mean skin temperature, and Burton's formula for mean heat loss calculations. In the recovery room patients were warmed up with an electric blanket, and shivering was ranked. The investigators observed similar temperature time courses in all groups, with normothermia on arrival to the operating room followed by a statistically significant decrease in tympanic and oesophageal temperatures during induction, and thereafter. They observed no differences between groups. Heat loss and shivering were reported as being similar in all three groups. Deriaz and colleagues concluded that the passive and active heat exchangers used did not prevent intraoperative hypothermia, reasoning probably because respiratory heat loss accounts for less than 30% of the total body heat loss. Since the second part of the cooling slope for group B was significantly reduced, they suggested that use of passive heat exchangers would seem to be advantageous for long procedures. However they also recommended that other warming devices be used to really prevent intraoperative hypothermia.

Konrad et al. (1996) studied the effects of a HME on bronchial mucus transport velocity (BTV) in the semi-closed inhalation anesthesia circle system in humans. In a

randomized controlled design, 22 patients undergoing major abdominal surgery were anaesthetized by similar means. After intubation, a HME (Bact/Viral HME, Pharma Systems AB, Sweden) was inserted between the endotracheal tube and ventilation tubing in 11 patients, while the other 11 served as controls—ventilating without a HME. Ventilation was assisted with a fresh flow of 3 liters in a semi-closed system, and a 2:1 mixture of nitrous oxide and oxygen. BTV was measured at the end of the operation. The two groups were comparable with regard to age, sex, pre-operative lung function, duration of mechanical ventilation, and dose of anaesthetics, however the investigators found no statistically significant differences in the BTV's. The investigators concluded that BTV does not improve with the use of a HME in the semi-closed circle system with a fresh gas flow of 3 Liters. They also recommended that lower fresh gas flows should be administered with modern anaesthesia machines, whereby the humidity and temperature of the inspired gases are further increased.

In another abstract, Rathgeber et al. (1996) reported on the impact of air conditioning on the calculated energy balance of man comparing HME and heated humidifier (HH) methods. HME (Medisize Hygrovent) and HH (Fisher and Paykel MR 730) efficiency were evaluated in a mechanically ventilated lung model simulating physiological heat and humidity conditions of the upper airways. Gas flow from the central supply was dry, and model temperature varied between 32 and 40 degrees C. By using an HH in the inspiratory limb the researchers were able to simulate a circle system, which yielded water-saturated inspired air at room temperature. The water content of this ventilated air was determined and compared with the moisture return of the HME.

Finally, energy balance was calculated according to thermodynamic laws. The investigators observed that both HME and HH were able to create physiological heat and humidity conditions in the airways. With the normothermic patient model, they found moisture return of the HME equal to that of the HH set at 34 degrees C. Increasing the temperature resulted only in reduced water loss from the lung. Heat and water input in the normothermic model was not possible, and was only seen to be effective with almost negligible amounts under hypothermic patient model conditions. Rathgeber and colleagues commented that both HME and HH were able to reduce pulmonary heat loss to 1-2 kcal/h, compared to losses of 8 kcal/h typically seen in intubated patients ventilated with dry air, and 6 kcal/h in adults with a minute volume of approximately 7L/min. They also suggested that HH do not offer significant advantages in heat balance compared to effective HME in normothermic as well as hypothermic patients. Ultimately, air conditioning in intubated patients was neither found to be a powerful tool for maintaining body temperature during long-lasting anesthesia nor a sufficient method of warming hypothermic patients in intensive care units.

Note: The HME's described in this section are generally small devices which are used for anaesthetic practice. These HME's function reasonably well at the low flow rates (less than 1.0 l/s) found within anaesthetic circuits. However, at flow rates of 0.5 l/s a driving pressure of up to 7.5 cm H2O is required, which increases further as the device becomes saturated with water vapor. Thus for most asthmatics they do not provide effective air conditioning of inspired air, therefore the only practical means of controlling their exercise

induced asthma is through drug treatment (Statement taken from Nisar et al. 1992, was applied by them to the Department of Health and Social Security report on HME's)

7. Discussion

Although the majority of the papers reviewed reported positive findings, there are methodological problems that must be considered when evaluating the effectiveness of HME's. The major concern when interpreting the results of studies that used thermocouples or probes to measure inspired/expired temperatures is determining whether the investigators accounted for the various potential errors associated with the temperature measurements. These measurement errors can be associated to probe size (thermal inertia), and condensation on the probe (which can be further broken down into change of phase and ice build up on the probe). Normally, when all of these factors have been accounted for one should see inspiratory and expiratory temperature fluctuation tracings that follow closely with their associated ventilation patterns. When considering the size of the probe, it is vital to understand that larger probes (in the order of a millimeter) will yield slower response times. This will lead to recordings of inspiratory and expiratory temperatures that do not fluctuate closely with the ventilation pattern, consequently blunting the air temperature responses and ultimately skewing the data. When the air (normally cold in the experiments reviewed) passes over the probe, condensation occurs in the form of a change of phase from a gas into a solid (ice). It is this process coupled with actual formation of ice on the probe that will also record

blunted inspiratory and expiratory temperatures, which ultimately will further contribute to skewing the otherwise normal close air temperature-ventilation association (Note: the reader should refer to the study by Johnson et al. 1987 to observe the effects of condensation on the probe in skewing the data by providing an actual performance coefficient of 33 instead of presenting the 0 that normal theory would have predicted for a no mask condition) What this means is that the probe will be recording the fluctuation of the ice temperature on the probe instead of the actual air temperatures. This will cause the appearance of more stable air temperature variations (ie. less of an increase in expiratory temperatures, and less of a fall in inspiratory temperatures) relative to ventilation. It is our feeling that lack of consideration for the temperature measurement errors may be a problem with studies that report positive findings with HME use in cold ambient conditions. Chances are that if the considerations were not mentioned then care was not likely taken to factor them in.

There is no hard evidence documented in the literature that supports the use of HME's as an ergogenic aid in the reduction of respiratory heat and moisture loss, as well as in enhancing performance/comfort time in cold environments.

Although the study by Rosen and Rosen (1995) suggests that one will tend to save approximately 15 grams an hour of respiratory moisture, this number does not seem to be significant nor will it likely lead to increased performance and comfort in the cold. Furthermore, when you consider the 2:1 ratio between water loss from the skin by perspiration (passive water loss from all body parts that doesn't necessitate sweating) and respiratory water loss (Kuno, 1956) it would seem more beneficial to focus on the

design of equipment that preserves water in all areas rather than only at the mouth. Some studies (Rosen & Rosen, 1995; Deriaz et al., 1992) also suggested that respiratory heat loss accounts for approximately 30% of total body heat loss, however there was no mention of the conditions that this number applies to. Research by Brajvcovic (1999) with subjects wearing arctic clothing exposed to -25 degree C conditions demonstrated losses of 150 watts (w) (88%) to heat flow, 1.1 w (0.6%) to convective respiration, 15 w (8.8%) to evaporative respiration, and 5 w (3%) to evaporative skin/heat loss. Therefore, respiratory heat loss (convective + evaporative) was found to account for only 16.1 w of the total 171 w of energy lost, a figure representing the proportion of respiratory heat loss to be only 9.4%. Again, it does not seem likely that preservation of this amount energy would lead to significant performance enhancement.

One might be tempted to argue back mentioning that even if HME's are not effective in reducing respiratory heat and moisture loss, they do increase inspiratory temperature and humidity therefore contribute to enhanced comfort and performance in cold conditions. It is worthwile to mention here that even a simple scarf may be able to do what these studies report. Furthermore, one cannot even be sure—due to the methodological considerations mentioned above—that the air temperature data reported is correct.

Some may even suggest that HME's have a significant impact on rewarming. This belief however, can be disputed by the results of Goheen et al. (1998) which provide proof that increasing inspiratory temperature (by about 60 degrees C above control) and humidity does not have an effect on rewarming performance using a heated humidifier

(HH). Therefore how can a passive device that doesn't even come close to providing the same level of heat and humidification as an active HH device have an effect on the comfort and performance of normal subjects in cold environments.

Given the above reasoning, there is no justification without further testing for the purchase and use of commercial HME's by the normal population for use in reducing heat and moisture loss, increasing inspiratory temperatures and relative humidity, and facilitating rewarming. It is true that positive results have been reported by these studies. However, have these results answered the real questions raised in the introduction? Can these findings be translated into better performance and comfort in the cold for the normal population? The report from Seifert et al. (1999) is about the only study reporting respiratory and cardiac advantages of using HME during exercise in the cold. The changes, however, are very marginal (between 3 and 6% improvement) and will unlikely provide significant physiological advantages as compared to not using a HME device.

We believe that the claims made by commercial manufactures cannot be verified scientifically to mean that these results will provide better performance and comfort. One cannot scientifically substantiate the claims of these manufacturers—ie. warms your cold body fast, eliminates lung chill, hands and feet stay warm longer, reduces dehydration, or it's the single most important piece of cold weather gear you'll ever own—based on the tentative findings of the current research. Nobody has actually tackled the performance enhancing question of HME's right on, therefore there is a need for more direct testing on HME's in normal subjects exposed to cold ambient conditions.

HME's have been in use in hospital environments for the past 30 years. Their primary function has been to condition inspired air during anaesthesia, as well as in tracheotemized or mechanically ventilated patients. The views of the current research reviewed however are mixed, and tend to suggest that HME's offer no real benefit in the prevention of intraoperative hypothermia and patient rewarming.

The only real hard evidence that supports the use of HME's as an ergogenic aid comes from research conducted on prevention of cold and/or exercise induced bronchoconstriction. These studies generally used spirometrical assessments coupled with exercise and cold exposure to determine HME effectiveness. Since a decline in spirometrical measurement such as forced expiratory ventilation in one second—along with a decline in other objective and subjective markers—are indicators of respiratory complications, and since most of the subjects experienced a reduction in this decline as well as decreased onset of symptoms or actual incidence of bronchoconstriction, it can be said with some confidence that HME's are effective in attenuating the risk of cold and/or exercise induced bronchoconstriction in at risk subjects. This would definitely classify HME's for use by this population as an ergogenic aid, as the devices would function to increase comfort, exposure, and ultimately performance time.

8. Conclusions

Previous research conducted on HME's have shown these devices to be effective in reducing the risk associated with the onset of cold and/or exercise induced bronchoconstriction in already predisposed individuals with existing respiratory condition. No real hard evidence exists in the literature however to support the use of HME's as a performance or comfort enhancer in cold ambient conditions for individuals who do not suffer from respiratory complications and are therefore not prone to cold and/exercise induced bronchoconstriction. Furthermore, the literature reviewed from the medical community seems to suggest that HME's offer no real benefit in conditioning air and preventing heat loss or intraoperative hypothermia.

9. Recommendations

In light of the evidence provided by this review, we have arrived at two recommendations for the use of HME's by the Canadian Forces:

1. If it is the intention of the Canadian Forces to use these devices with normal personnel to enhance performance during cold exposure, then we recommend that further more specific studies be commissioned that more accurately determine the ergogenic effect(s)—if any—of these devices in cold ambient conditions in non-diseased (ie. respiratory complications) subjects.
2. HME use is recommended for those CF personnel who are exposed to cold and/or exercise conditions and are already prone to bronchospasm.

10. References

1. Brajvcovic, D. (1999). Effect of direct and indirect hand heating on hand comfort and finger dexterity during cold exposure. Ph.D Thesis, University of Toronto, Toronto, Canada, 266p.

2. Brenner, A. M., Weiser, P. C., Krogh, L. A., & Loren, M. L. (1980). Effectiveness of a portable face mask in attenuating exercise-induced asthma. Journal of the American Medical Association, 244(19), 2196-2198.

3. Collis, M. L., Steinman, M., & Chaney, R. D. (1977). Accidental hypothermia: An experimental study of practical rewarming methods. Aviation Space and Environmental Medicine,48(7), 625-632.

4. Deriaz, H., Fiez, N., & Lienhart, A. (1992). Comparative effects of a hygrophobic filter and a heated humidifier on intraoperative hypothermia [CD-ROM]. Annales Francaises d'Anesthesie et de Reanimation,11(2), 145-149. Abstract from: Dialog File 73: Embase Item: 1992157913.

5. Eiken, O., Kaiser. P., Holmer, I., & Baer, R. (1989). Physiological effects of a mouth-borne heat exchanger during heavy exercise in a cold environment. Ergonomics, 32(6), 645-653.

6. Evaluation report: Heat and moisture exchangers. (1987). Journal of Medical Engineering and Technology, 11(3), 117-127.

7. Goheen, M. S . L, Ducharme, M. B., Kenny, G. P., Johnston, C. E., Frim, J., Bristow, G. K., & Giesbrecht, G. G. (1997). Efficacy of forced air and inhalation

rewarming by using a human model for severe hypothermia. Journal of Applied Physiology, 83(5), 1635-1640.

8. Gravelyn, T. R., & Eschenbacher, W. L. (1986). A respiratory heat and moisture exchanger can protect against bronchoconstriction induced by isocapnic hyperpnea with dry air. American Review of Respiratory Disease, 133(4), supplement, A 319.

9. Seifert, J.G., Bacharach, D., Nelson, A. (1999). The effectiveness of a heat excahnger mask on spirometry and physiological data during exercise in the cold. Human Performance Laboratory Report, St.Cloud State University.

10. Johnson, D. L., Bos, C. J., Rivington, R. N., Dodge, P. (1987). A technical and functional assessment of cold weather masks in severe cold conditions. Research and Standards Division, Bureau of Radiation and Medical Devices Report.

11. Konrad, F., Mezody, M., Goertz, A., Marx, T., & Georgieff, M. (1996). The effect of a heat and moisture exchanger (HME) on bronchial mucus transport in a closed inhalation anesthesia system [CD-ROM]. Anaesthesist, 45(9), 802-6. Abstract from: Dialog File 155: Medline Item: 08863729 97088552.

12. Kuno, YAS. (1956). Human Perspiration, p. 416. R. F. Pitts (ed.). Springfield: c.c. Thomas.

13. Levin, S. (1978). [Letter to the editor]. Prevention of exertional asthma. The New England Journal of Medicine, 299(4), 201.

14. Mekjavic, I. B., & Eiken, O. (1995). Inhalation rewarming from hypothermia: An evaluation in –20 degree C simulated field conditions, Aviation Space and Environmental Medicine, 66, 424-9.

15. Mekjavic, I. B., & Eiken, O. (1996). Thermodynamic characteristics of a prototype respiratory heat and moisture exchanger. In Y. Shapiro, D.S. Moran, & Y. Epstein (Eds.), Environmental Ergonomics: Recent Progress and New Frontiers (pp. 143-146). London: Freund.

16. Nisar, M., Spence, D. P. S., West, D., Haycock, J., Jones, Y., Walshaw, M. J., Earis, J. E., Calverley, P. M. A., & Pearson, M. G. (1992) A mask to modify inspired air temperature and humidity and its effect on exercise induced asthma. Thorax, 47, 446-50.

17. Rathgeber, J., Weyland, W., Bettka, T., Zuchner, K., & Kettler, D. (1996). Is reduction of intraoperative heat loss and management of hypothermic patients with anesthetic gas climate control advisable? Heat and humidity exchangers vs. Active humidifiers in a functional lung model [CD-ROM]. Anaesthesist, 45(9), 807-13. Abstract from: PubMed Query: Medline Item: PMID 8967598, UI 97030880.

18. Rosen, A. E., & Rosen, M. (1995). Effect of a face mask on respiratory water loss during sleep in cold conditions. Wilderness and Environmental Medicine, 6, 189-195.

19. Schachter, N. E., Brown, S., Lee, M., & Gerhard, H. (1978). [Letter to the editor]. Prevention of exercise induced asthma. The New England Journal of Medicine, 299(21), 1194.

20. Stewart, E. J., Cinnamond, M. J., Siddiqui, R., Nicholls, D. P., & Stanford, C.F. (1992). Effect of a heat and moisture retaining mask on exercise induced asthma. British Medical Journal, 304, 479-480.

21. Testing and Evaluation Report: The Polarwrap Exchanger. (1998). Intertek Testing Services: Engineering Test Group, Atlanta, GA. Intertek ETG project number J9800989.

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The purpose of this paper was to serve as a brief literature review overviewing the current state of knowledge

pertaining to respiratory heat and moisture exchangers (HME's). Recommendations were extracted from the review with the intention of informing the Dwyer Hill Training Centre so that an informed decision could be made regarding further laboratory testing of HME's as well as setting policy regarding the use of HME's as an ergogenic aid for the Canadian Forces (CF). Detailed for the reader were the general physical properties and mechanism of function of most modern HME's, as well as their application to respiratory heat and moisture retention, reduction of cold and/or exercise induced bronchoconstriction, and medical environments. Although the majority of the papers reviewed reported positive findings—with the only real challenges coming from the medical community—no hard evidence was found to support the use of HME's as an ergogenic aid in the reduction of respiratory heat and moisture loss. However, there may be some merit for the use of HME's as performance enhancers by those individuals who are predisposed to respiratory complications that are further aggravated by cold and/or exercise exposure. In light of the evidence provided by this review, it is the recommendation of the authors that further more specific and thorough testing be commissioned to evaluate the heat and moisture sparing properties of HME's and their possible application as an ergogenic aid to CF personnel during cold exposure. We do feel comfortable however with recommending HME use by those military personnel who have existing respiratory conditions that might be aggravated by cold and/or exercise exposure.

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Respiratory heat loss, Moisture loss, Cold bronchoconstriction, Asthma, Spirometry

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